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Nanotechnology: Threats and Deterrent Opportunities by 2035

by

Christopher P. Hauth, Lt Col, USAF

A Research Report Submitted to the Faculty
In Partial Fulfillment of the Graduation Requirements

17 February 2010

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About the Author

Lieutenant Colonel Christopher P. Hauth is an Aircraft Maintenance and Logistic Readiness Officer commissioned from the United States Air Force Academy in 1988. He attended the Aircraft Maintenance Officer Course at Chanute AFB, Illinois, and was assigned to the 46th Test Wing, Eglin AFB, Florida, supporting test and evaluation of improved and new avionics software and munitions on A-10, F-4, F-15, F-111 and UH-1N aircraft. Following this assignment he was posted as the USAF Exchange Officer to the Japanese Air Self Defense Force. Upon his return from Japan he cross-trained in Logistics Readiness and served as the Supply and Fuels Officer at the 92d Air Refueling Wing supporting KC-135s. He was assigned as a Liaison Officer with the Royal Saudi Air Force, and then was a Squadron Maintenance Officer for F-16s at Misawa Air Base, Japan. Lieutenant Colonel Hauth became the first commander of the 55th Aircraft Maintenance Squadron, Offutt AFB, Nebraska, responsible for national command and control platforms, intelligence and surveillance aircraft, and the Defense Threat Reduction Agency's OPEN SKIES treaty platforms. He was then assigned to the Air Staff in the Studies & Analyses, Assessments and Lessons Learned Directorate, where he examined combat and Air Force investment decisions for the Air Force Secretary and Chief of Staff. After leaving the Pentagon, he served as the Deputy Commander of the 305th Maintenance Group, McGuire AFB, New Jersey, and the 332d Expeditionary Maintenance Group providing combat-ready aircraft and required munitions in support of coalition forces in Iraq.

INTRODUCTION

"Scientia potestas est" (Knowledge is Power). Francis Bacon[1]

As Doctor Seuss' Horton the elephant discovered when dealing with Whoville, size is not an indicator of potential.[2] The tiniest of specks can contain untold possibilities as the people of Whoville demonstrated when they changed Horton's world view. One just has to listen.

This research paper discusses the transformational potential of nanotechnology, by the year 2035, to threaten U.S. national security, but also to provide unique deterrence options. Nanotechnology is increasingly inextricably linked to America's global economic competitiveness and national security. By 2035 U.S. leadership in nanotechnology will enable a nanotechnology-empowered military as a critical combat multiplier in support of our national security. The last Secretary of Defense believed that a primary lesson of the Global War on Terror was that our exploitation of military capabilities was more crucial to our success than sheer mass.[3] Nanotechnology offers a tremendous opportunity to transform our military capabilities.

The term nanotechnology has a wide range of uses, from layered coatings that improve common commercial products to science fiction stories foretelling atomic-sized machines that repair humans from the inside out. This paper uses the U.S. National Nanotechnology Initiative definition of nanotechnology. It defines nanotechnology as understanding and controlling matter at "dimensions between approximately 1 and 100 nanometers (nm), where unique phenomena enable novel applications."[4] These unique phenomena occur only on a scale where intermolecular forces become more important than standard Newtonian physics. To put this scale into perspective, Joel Garreau says nanotechnology "means manipulating the unimaginably

small" and gives us a superb frame of reference by equating a nanometer to "five carbon atoms in a row…."[5]

Nanotechnology, however, is about much more than dealing with the very small. M.C. Roco[6] describes nanotechnology as a major advance in technology due to a convergence of the fields of science and engineering allowing us to "see and touch" atoms and molecules, "where the fundamental principles of life can be found."[7] The impetus for nanomaterials came from quantum theory, since nanomaterials are governed by the laws of quantum physics. In other words intermolecular forces at the nanoscale give these materials unique properties. For example the ratio of surface to core atoms on a nanoparticle is very large, which changes the electronic structure of the core atoms and its anisotropy[8] may be quite different from bulk systems.[9] It is also important to differentiate nanotechnology from nanoscale technology, which deals with items less than 100 nm in size, but not "designing and building machines in which every atom and chemical bond is specified precisely."[10]

This paper highlights existing and likely advances in scientific and technical[11] understanding of nanotechnology. It outlines how this knowledge might interact with the strategic environment, and provides some ideas for using nanotechnology to deter adversaries and concludes with recommendations for further research.

NANOTECH TODAY

"If I were asked for an area of science and engineering that will most likely produce the breakthroughs of tomorrow, I would point to nanoscale science and engineering." Neal Lane Former Assistant to the President for Science and Technology[12]

Currently nanotechnology is in its early stages, but the science is rapidly advancing. Today, nanotechnology deals mainly with passive nanostructures[13] such as nano-tubes, layers and particles. Even at this level of development, however, global investment in nanotechnology is having a profound impact on advancing the frontier of scientific and engineering knowledge.[14]

These advances are being driven by a convergence of advances in science and engineering fields funded by governments and industries that have recognized its vast commercial potential.[15] "What is interesting about nanotechnology is that it functions as a technological multiplier. It moves other technologies to new levels."[16] Already fields as diverse as manufacturing, electronics, and medicine are being transformed due to our better understanding of the nanoscale environment and creation of tools to manipulate matter on this scale. These successes have formed a self-perpetuating innovation loop. For example, biotechnology companies are funding advances in nanotechnology to provide new tools to produce better pharmaceuticals. The resulting technological advances are then applied to the science of computing, which then improves researchers' understanding of critical, computationally intensive fields of study like DNA.[17]

These complementary scientific and engineering advances, applied to the field of material science, have led to nanomaterials used in various commercial applications today. Nanomaterials are materials made by combining chemical engineering and material science to produce nanoscale materials that enable stain resistant apparel, super-hard ceramics and ultra-fine powders.

On the other hand, nanomachines, which require self-replication to be commercially viable,[18] are not yet commercially available. Currently, however, much research is focused on creating the conditions for future self-replicating nanotechnology. Nanomachines will come from the convergence of advances in material science, mechanical engineering, robotics and biotechnology.[19] The huge potential of nanomachines, like in-vivo medical devices,[20] sensors, and nano-surveillance systems, is being recognized with concomitant Research and Development (R&D) funding from industries and governments.[21]

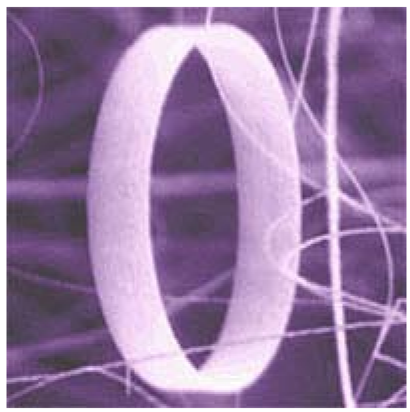

Figure 1: High Magnification Image of a Free-Standing Crystal Zinc Oxide Nanoring[22]

Nanotechnology-infused manufacturing is already in great demand due to its ability to discretely control desired material properties. It "aims at building material structures, components, devices/machines, and systems with nanoscale features…."[23] Specifically operating in nanoscale, like the Nanoring imaged in figure 1, enables materials with reduced mass, enhanced performance, improved durability, enabling multifunctionality and reduced cost. A very promising example is fluorescent sensors.[24] Nanoparticle-fluorescent polymer, or 'chemical nose,' sensors have recently been used to detect and identify proteins with an accuracy of 94 percent, demonstrating huge potential in medical diagnostic applications.[25]

A widely used and researched nanostructure with tremendous potential is the Carbon Nanotube (CNT). A CNT (figure 2) is a tubular form of carbon with a diameter from 1 nm to a

few microns.[26] “Because of their unique self-assembled and atomically perfect structures, carbon nanotubes exhibit unusual electrical, mechanical, and chemical properties.”[27] These properties include “the ability to carry exceptionally high current densities in long molecularly perfect ‘wires’ and unusually high mechanical strength at the limit of small ‘fiber’ diameters….”[28] CNTs are already used as structural reinforcements and in lithium-ion batteries. Future applications include chemical sensors, portable X-ray machines, and extremely lightweight and strong materials that will dramatically reduce the weight of cars and spacecraft.[29]

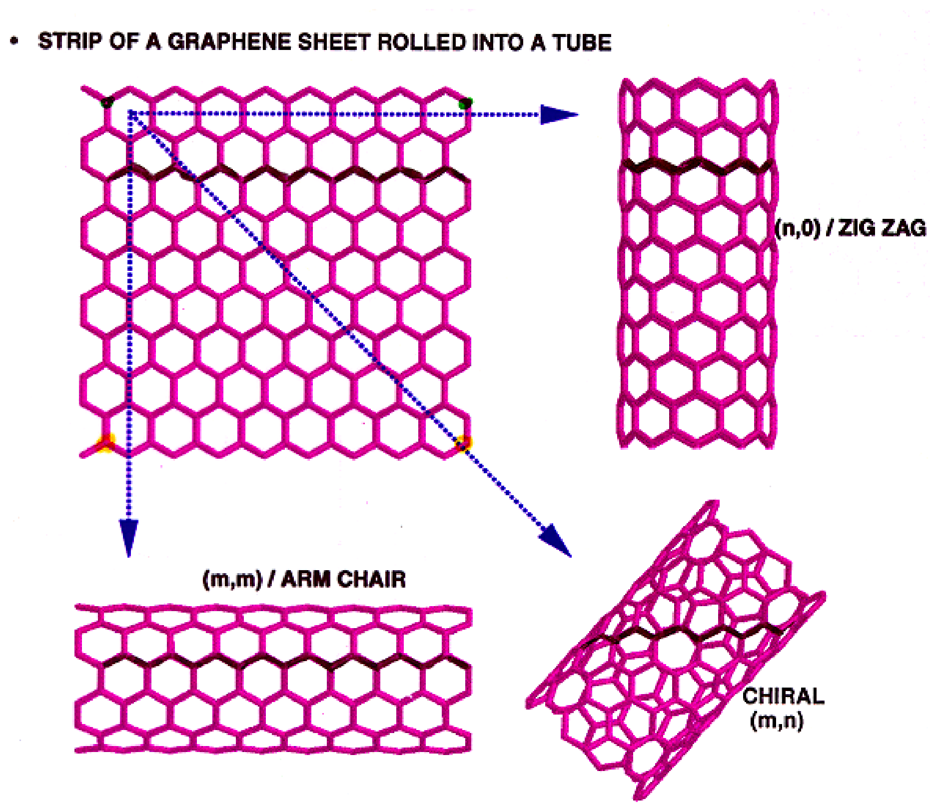

Figure 2: Carbon Nanotube Diagram Courtesy of Meyyappan[30]

Nanoparticles offer exciting opportunities in various fields. For example “magnetic nanoparticles are useful for a wide range of applications from data storage to medicinal imaging.”[31] Bob Fox from Idaho National Laboratory says, "Nanoparticles are the scientific

gold rush of the next generation. They'll change our lives the way personal computers have."[32] Nanoparticle properties are very dependent on size, so harnessing their true potential requires producing them to specific sizes. Many commercial and academic R&D programs have reported progress in this area[33] allowing even more use of nanoparticles in commercial products, such as coatings and powders, usually created through chemistry. Manufacturing using ultrafine powders provides a more even mixture leading to improved properties, such as stain resistance and ease of cleaning.[34] True nanoparticle coatings have different properties at the nanoscale, for example Titanium Dioxide is a brilliantly white substance that is used as a pigment in paints, but a layer "only 15 nm thick is transparent and can be applied to glass to make it self-cleaning."[35] One new nano-infused product with exciting uses in multiple areas is Demron™ radiation shielding garments.[36] The size of nanoparticles allows them to be more evenly spread forcing "each x-ray to contend with more different substances in a given space."[37]

Another nanotechnology advancement currently being researched is nanowire. "The progress in experimental techniques has made it possible to synthesize ultrathin metal nanowires with diameter down to atomic sizes."[38] Most frequently mentioned uses for nanowires, like putting millions more transistors on a microprocessor, are not yet feasible, but one demonstrated use is reducing the risk of titanium implant failure. Muscle tissue does not always adhere to titanium, but researchers have discovered it can anchor itself to nanowire-coatings.[39]

NANOTECH IN 2035

By the year 2035 the use and impact of nanotechnology will have grown far beyond simple nano-infused products. Senators Joe Lieberman and George Allen state that nanotech has the "potential to transform every aspect of our lives."[40] The ability to work in nanoscale, "to create large structures with fundamentally new properties and functions" is "leading to unprecedented understanding and control over the basic building blocks of all natural and man-made things."[41] By 2035 nanotechnology will have reached enough of this potential to have pervasively changed our world. Self-assembly, enabling "large-scale circuits to be created in test tubes rather than in multibillion-dollar factories,"[42] may even be just around the corner.

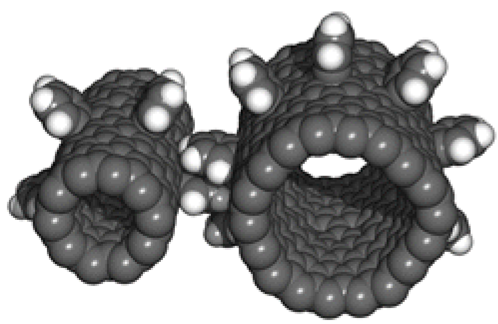

Figure 3: Computer-Simulated Picture of Carbon-Nanotube Gears [43]

Wang believes that "nanotechnology will emerge as a strategic branch of science and engineering, fundamentally restructuring technologies" as diverse as manufacturing, medicine, computation and communication for use in education, defense, and transportation.[44] For example nanoscale machines made from CNT gears, as depicted in the computer simulation above, will be in widespread use. This ability to build items with molecular perfection will have transformed our everyday lives. Nano-materials will make products cheaper, lighter, and stronger[45] and have science fiction-like interactivity. Our products will communicate with each other and us. Our clothing will be imbedded with invisible-to-the-naked-eye electronics. Our

buildings will be stronger, safer and more environmentally friendly. Nanotechnology will have replaced most microtechnology in the global commercial market. Drexler's predictions of "a general molecular engineering technology" in his ground breaking book, "Molecular Engineering: An Approach to the Development of General Capabilities for Molecular Manipulation," will have come to fruition.[46]

Nanobiotechnology of the future will be intertwined with our lives from cradle to grave and will greatly improve medical care. The expanding ability to read a person's genetic makeup will enable individual diagnostics and medical treatments with nano-devices, making gene sequencing more efficient.[47] Remote and in-vivo devices will lead to more effective and less expensive health care.[48] Researchers are already predicting nano-biotech will provide new formulations and routes for drug delivery for optimal drug usage.[49] Nanotechnology will also lead to rejection-resistant transplant organs and better sensors for early detection and prevention of diseases.[50]

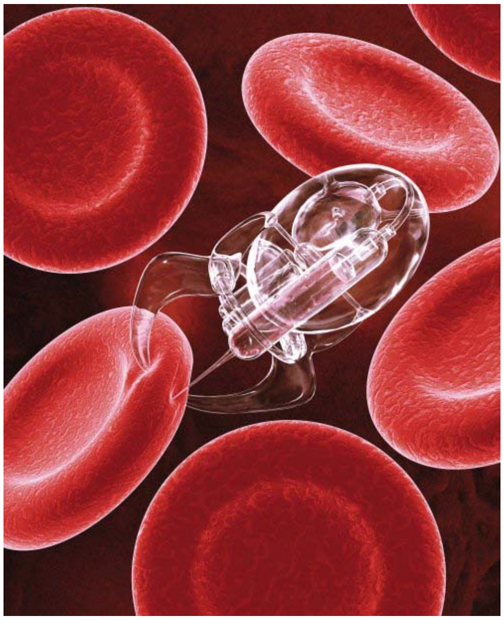

Figure 4: Image of Nanotechnology Machine Applied in Bloodstream.[51]

By 2035 the confluence of nanotechnology and biotechnology will lead to fundamental scientific and engineering advancements. "The road to nanotechnology, as Drexler described it in his *PNAS* paper, and in much greater detail in *Nanosystems*, was a more or less straightforward extension in biology."[52] Oliver predicts that in 30 years the 'Biotech Age' will be in its mature phase and will be a greater economic and social impact than was the introduction of the car and computer chip combined.[53] Specifically, he predicts that by 2050 legacy medicine, which focuses on specific threats, will be replaced by genetic approaches that identify and target the actual source of the problem.[54]

One way nanotechnology will be tremendously useful is in medical treatments using "nano-particle based platforms for detection and treatment of cancer"[55] or even nanoscale devices to manipulate biological activity to cure a wide range of diseases.[56] These devices are smaller than a human cell, which are 10 to 20 thousand nm in diameter. A 50 nm device could operate inside a cell while one less than 20 nm could move through blood vessel walls. "As a result, nanoscale devices can readily interact with molecules on both the cell surface and within the cell." [57] Future nanoscale devices,[58] as simulated in the picture above, are one possible avenue for administering future genetically designed cures.

By 2035 nanotechnology will have transformed computing by continuing to create faster, smaller computers with increased storage capacity leading to ubiquitous computing (UC).[59] Processors with declining energy use and declining cost per gate will lead to increasingly efficient, small, mass storage devices that will possibly allow data storage of up to 10^{15} bytes/cm^2 (see figure 5). This paper does not predict quantum[60] computing (QC),[61] within 25 years, but an interim step toward QC[62] may be "very fast three-dimensional molecular

circuits…based on devices such as nanotubes."[63] This paper does predict that nanotechnology applied to data storage will synergistically engage with breakthroughs in our understanding and use of carbon nanotubes leading to exponential advances in all areas of computing. For example, as magnetic material is reduced in size, it acquires simpler magnetic domain structure eventually leading to single domain particles or nanoparticles which offer exciting opportunities in high capacity data storage.[64] UC, however, is much more than simply improved computers and networks, it is "….calm technology…. a paradigm shift where technology becomes virtually invisible in our lives. Instead of having a desk-top or lap-top machine, the technology we use will be embedded in our environment."[65] Sensors are already embedded in many products, but by 2035 nanotechnology-infused sensors will be extremely tiny, inexpensive and interconnected. Already scientists at Lawrence Berkeley National Laboratory have developed sensor systems that "both detect nanoparticles and rely on the formation of nanoparticles that have been developed as sensing species."[66] The commercial success of nanotechnology-enabled products will play a vital part in spreading computing power and sensors leading to UC. Nanotechnology will be in our very clothes, "nanofibers could be used for textiles with integrated sensors and electronic connections."[67] These devices will calculate and communicate and form "networks that are flexible and reconfigure themselves continuously."[68] "By 2020, it (UC) will dominate our lives."[69]

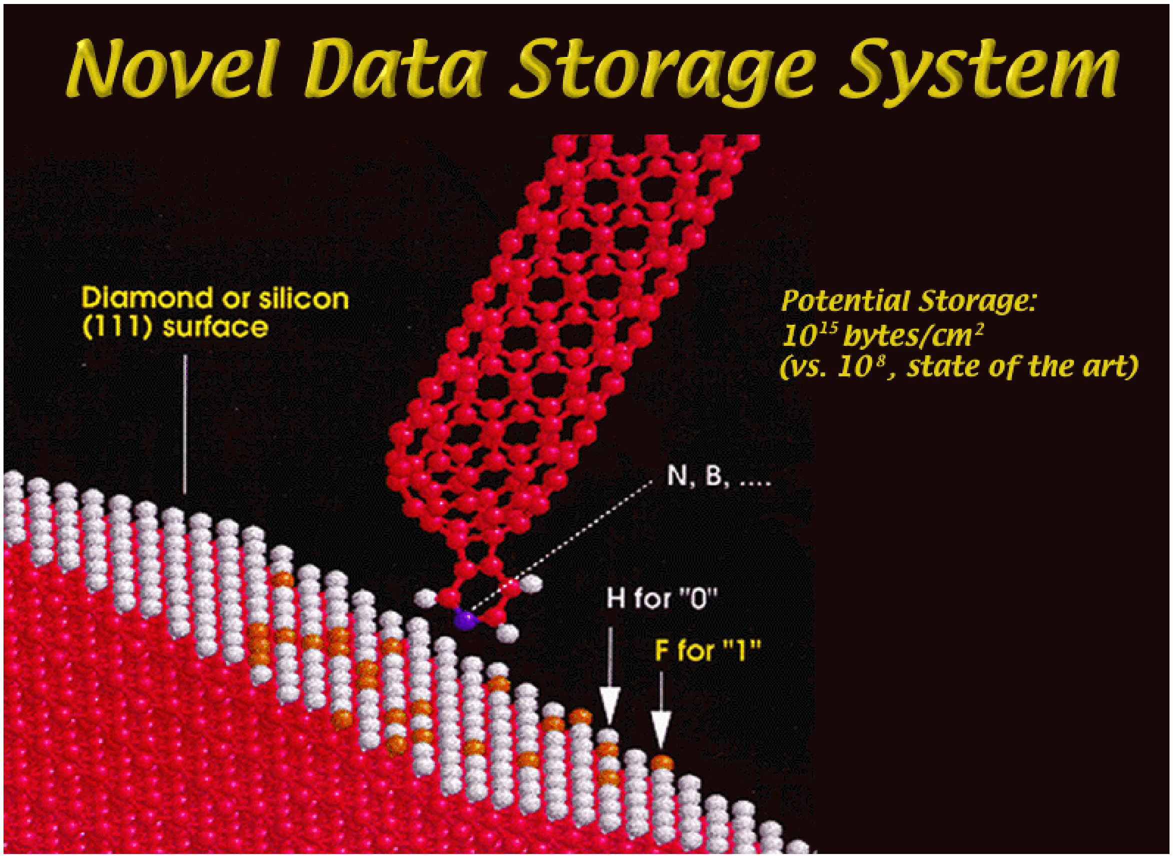

Figure 5: A Novel Data Storage System[70]

FUTURE THREATS

In 25 years, threats to US national security will come from adversaries using converging scientific and engineering nanotechnology advances. We must not underestimate our vulnerabilities from nanotechnology-enabled enemies, whether nation states or terrorists. During the 2009 National Academy of Science's Avoiding Technology Surprise for Tomorrow's Warfighter Symposium, specific areas of concern for Combatant Commanders included the threat from lack of understanding of "…how adversaries might employ rapidly evolving and often commercially available technologies.…" such as nanotechnology.[71] This is understandable as ubiquitous nanotechnology and sensors can create orders of magnitude increases in transparency and lethality.

By 2035 current advances in nanotechnology-infused material science could impact conventional military force-on-force engagements. Advances in nanomaterial science have the potential to drastically improve everything from main battle tank armour to personal protective vests impervious to even armour-piercing bullets.[72] This nanomaterial-based "lightweight transparent armour,"[73] if infused with nanostrands (seeigure 6), could perhaps even offer protection from directed energy weapons. Areas such as amorphous metal (which has an irregular nanoscale structure) might be one starting point for this improved armour. It has "about double the elastic strain of multicrystalline metal" with double the tensile strength and hardness of steel and three times the fracture strength.[74] Another possible avenue to improved armour is nanoscale additives in composites such as "clay-derived layered silicates in thermoplastics" which have reduced flammability, doubled hardness, and 50 percent increased tensile strength and fracture toughness.[75] The Air Force Research Laboratory (AFRL) at Wright-Patterson AFB has demonstrated a nanostrand imbedded polyester/elastomer fabric (see figure 6) that

suppresses 625KV[76] These two nanomaterials used in a composite are just one possible way our enemies could one day employ improved tank or personal protective armour against US interests. Both of these developments would pose serious challenges for US or allied combat, peace-keeping or even stability operations. The repercussions of nanomaterial science and nanoenergetics on munitions R&D[77] will be harder, stronger penetrators with vastly increased explosive force.

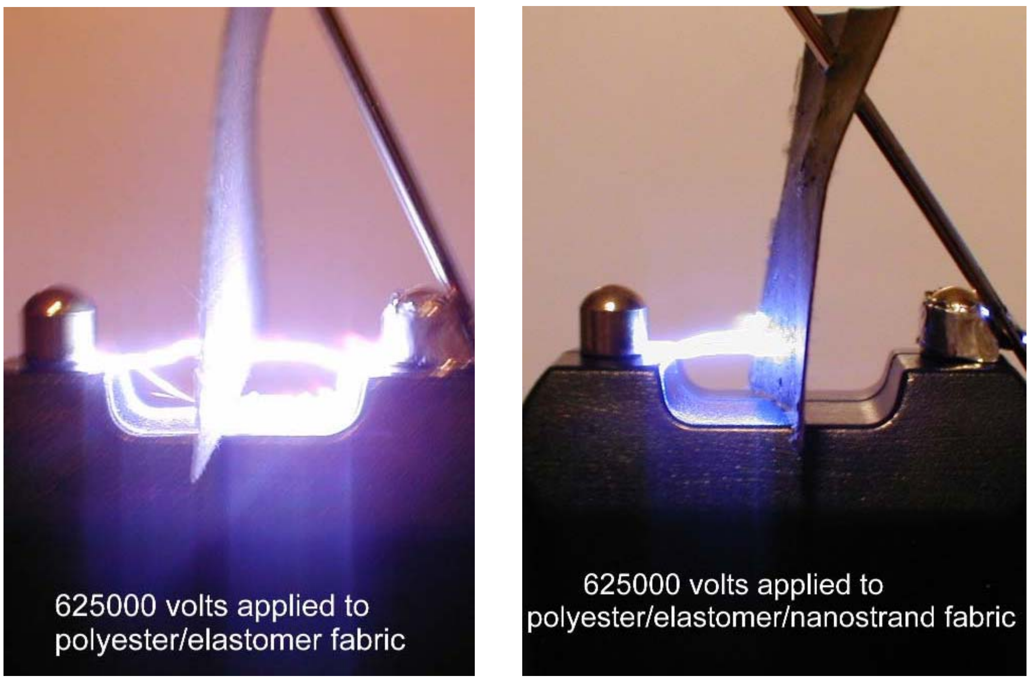

Figure 6: 'Voltage Suppression-Proof of Concept' without and with Nanostrands[78]

Nanoparticles used as nanotaggants,[79] could greatly enhance transparency to a point that endangers U.S. national interests. Advanced nanotaggants coupled with ubiquitous computing and nanotechnology-infused sensors will give us and our enemies the ability to track people and their associates. This enables surveying what is known in the military as the Human Terrain System[80] and is very relevant in unconventional warfare. In unconventional warfare knowing

who holds power and who is related to who is crucial to victory; "the path to victory in a counterinsurgency (COIN) runs through the indigenous population … (or) centers of gravity."[81]

This research paper found it credible that ongoing basic research with regard to safely creating, using and detecting nanoparticles would produce safe-for-human-use nanoparticles[82] for creating nanotaggants and sensors for detecting them at a distance.[83] In fact, basic handheld nanoparticle detectors are already commercially available.[84] Creating a nanoparticle to tag someone is only one part of the equation; it must also lend itself to being detected. Lawrence Berkeley National Laboratory scientists are using the unique properties of nanoparticles to develop nanoparticle-detecting sensors made from nanoparticles.[85] University of Florida researchers (using a 'lab on a chip' made with bionanotechnology building blocks) feel confident of making 'smart dust' nanoscale detectors that change color when exposed to conditions ranging from biological weapons to spoiled food.[86] One type of sensor developed by researchers at The Molecular Foundry[87] are caged quantum dots,[88] which are nanoparticles that produce colors that allow you to know what you've detected. Any one of these advances in nanoparticles and sensors,[89] extrapolated 25 years into the future, could be the basis for a nanotaggant system by 2035.

A nation, group or individual could use nanotaggants against U.S. interests by placing specific nanotaggants on targeted individuals or by distributing a more generic nanotaggant in a thoroughfare used by multiple attendees to high level meetings. During the meeting, especially in a high-context culture[90] given to personal contact, nanotaggants would be transferred, giving an adversary Human Terrain System information. Having been identified and tracked, meeting attendees could then be targeted for further intelligence collection activities. Nanotaggants in the

hands of our enemies would make social transparency a threat to U.S. national security and put the US on the receiving end of the ancient lesson “knowledge is power.”

DETERRENCE

"Deterrence is a state of mind brought about by the existence of a credible threat of unacceptable counteraction." It is "the prevention from action by fear of the consequences." Joint Publication 1-02, Department of Defense Dictionary of Military and Associated Terms[91]

Advances in nanotechnology will present unique opportunities to deter future adversaries from using nanotechnology to threaten US national interests.[92] In addition to deterrence as defined above, this chapter will discuss the possibility of preventive control. This means controlling nanotechnology proliferation, so our adversaries do not have access to it. The international community currently uses this deterrent method with regard to nuclear technology through preventive arms control.

"Information is the currency of victory on the battlefield."[93] Attribution is crucial to deter adversaries, whether individuals, groups, or nations, therefore determining whom to hold accountable is a key requirement of deterrence. Intelligence[94] will become even more relevant as scientific and engineering advances continue to increase the lethality of individuals and groups.[95] Just as we need to understand the technological viability of the threat, we also need to know the enemy and their intent and willingness to implement the threat. Targeted nanotaggants[96] could add personal context information to terrorist networks or rogue nation states. Once we know the adversary's Human Terrain System we can covertly employ UC in technologically advanced areas or emplace nanotech interconnected sensors as invisible eyes and ears to determine their technological capabilities. Nanotechnology-enabled increases in computing power could then identify useful patterns, from the data collected by the taggants, the proliferation of sensors and UC, all available in 2035. These patterns will enable attribution of attacks, or attack plans.

Deterrence by denial[97] might also be viable with regard to nanotechnology-enabled adversaries. For example an adversary might not use nanotechnology for nefarious purposes if his cost-benefit analysis showed using it was not in his best long-term interest. A terrorist might also be deterred if we leveraged the social transparency enhancing aspects of nanoparticles as nanotaggants to make him believe he would be detected and held accountable. It is also important to convince an adversary that an attack would not succeed. Advances in nano-filters[98] and introduction of nanotechnology-enabled defensive and offensive weapon systems, from tanks with improved armour to nanoenergetic munitions with nanotech penetrating shells, into the U.S. inventory might also lead others to forego the expense of incorporating nanotechnology in their weapon modernization efforts.

One long standing deterrence option is preventing access to the threatening technology. This is a much more viable option if the technology is difficult to acquire. Due to the huge global investments in nanotechnology R&D, the technology for creating nanotechnology products, as well as continuing science and engineering advances, is quickly becoming inexpensive and globally pervasive. In economic terms its tremendously expanding influence on the global market has made successful anti-proliferation actions extremely difficult if not impossible.[99] The global community could still attempt a Collective-Actor Deterrence[100] to prevent access to nanotechnology knowledge, but nanotechnology is continually becoming less dependent on limited or costly equipment. Commercial success of nanotechnology has created a synergistic resonance of scientific discoveries, a concomitant reduction in manufacturing cost, and a global proliferation of nanotechnology knowledge.[101] Controlling this knowledge does not appear to be a viable option.

CONCLUSION

> "The Moving Finger writes; and, having writ, moves on: nor all thy Piety nor Wit Shall lure it back to cancel half a line, Nor all thy Tears wash out a Word of it."[102]

Due to its increasing role in the global economy nanotechnology will continue to be a tremendous enabler in a wide range of fields creating huge economic and military opportunities. However, in the hands of our enemies, this same transformational potential will pose new threats to our national security. Continued U.S leadership in nanotechnology can offset this threat by creating a nanotechnology-empowered military and providing new deterrent options.

Leadership in nanotechnology is crucial to U.S. economic success and national security. In addition to diplomatic, information, and military strength, economic might is one of the primary powers the U.S. has to protect itself and project influence. In response to nanotechnology's huge economic potential, the President created the National Nanotechnology Initiative (NNI). The NNI has assisted in making the U.S. the global leader in nanotechnology, but the global competition has begun, as demonstrated by numerous countries' indigenous nanotechnology initiatives. Industries and governments around the world are independently investing in nanotechnology R&D. This investment, coupled with the synergistic impact of nanotechnology on multiple areas, will lead to an exponential increase in ubiquitous knowledge. Continued global leadership, with regard to nanotechnology R&D and nanoproduct production, will be crucial to America's ability to afford its unrivalled national powers. For example, both diplomatic and military powers are anchored on the bedrock of our economic strength. A very strong economy is required to support a military able to effectively operate on a global scale. Diplomacy also relies on funding for international programs, ranging from peace keeping to foreign aid. A viable military option is also required to provide credibility to diplomacy during

times of tense international relations. Nanotechnology, as a fundamental design science, is the key to future U.S. economic competitiveness required for all these national powers. Nanotechnology's transformation of the global economy is irrevocably tied to U.S. national security.

Nanotechnology's transformation of the global economy will create new threats to U.S. security. Its unique properties applied to material science will lead to stronger armour, more effective munitions, improved personal protective equipment and nanotaggants. The convergence of advances in material science, computing and biotechnology will lead to increased social transparency. Americans will be vulnerable to nanotaggants created from advancements in nano- particles, sensors and detectors. Nanotaggants will allow adversaries to 'tag' a target for tracking and data collection. U.S. investments in nanotechnology R&D will lead to advancements enabling our military to detect and neutralize nanotaggants as well as protect themselves from improved munitions as well as defeat their adversary's armour.

Nanotechnology also offers possibilities in the realm of deterrence. In line with the quote "Knowledge is Power" nanotechnology will revolutionize information gathering and knowledge vulnerability. Nanotechnology applied to computing and sensors will lead to ubiquitous computing (UC) enabling U.S. forces to leverage UC in technologically advanced areas, or emplace nanotech interconnected sensors in undeveloped areas, using these sensors as invisible eyes and ears to better understand and defeat an adversary.

In light of nanotechnology's potential to impact military capabilities this paper recommends further research to determine if U.S. military prioritization of nanotechnology R&D is commensurate with its potential impact on our future defense capabilities and deterrence options. One specific research area of growing importance is the ability of nanomaterial,

whether completely nano-designed or nano-infused as in ceramic sprays, to protect electronics and building material from electromagnetic pulses or directed energy weapons. The same research could also explore nanofilters as protection against nanoparticles as well as detectors for nanotaggants.

A quarter century ago The Concise Columbia Encyclopedia did not have an entry for nanotechnology.[103] Today's on-line Columbia Encyclopedia is full of information on nanotechnology.[104] Feyman said, "In the year 2000, when they look back at this age, they will wonder why it was not until the year 1960 that anybody began seriously to move in this direction."[105] The question before us today is what our leaders in 25 years will think of how we addressed the implications of nanotechnology with regard to our future security.

America's future national security must be nanotechnology-empowered. This requires continued U.S. leadership in nanotechnology. We must be able to employ nanotechnology-enabled military and intelligence gathering hardware to counter nanotechnology-derived threats. This envisioned future requires an even larger current investment in science and technology, because, as this research has shown, the threat from nanotechnology-enabled adversaries is very credible. It is an economic and security imperative that America listen, as Horton did, and prepare now for nanotechnology's impact on the U.S. national security.

Notes

[1]In Rebus web site, Latin Language and its Vicinities On-line, http://www.inrebus.com/index.php?entry=entry080210-160826, accessed 15 January 2010.

[2] Theodor Seuss Geisel wrote books under the name Dr. Seuss and the main character of his 1954 book *Horton Hears a Who!* is an elephant named Horton. Horton hears voices coming from a small speck of dust and discovers a world of microscopic-sized inhabitants known as Whos who live in Whoville.

[3] U.S. Congress, House, Rumsfeld, remarks before the Committee on Armed Services regarding the President's 2005 Budget Request for the Department of Defense, Washington, D.C., 4 February 2004, on-line at www.iwar.org.uk/military/resources/2005-dod-budget/04-02-2004-rumsfeld.htm.

[4] NNI website, http://www.nano.gov/html/about/symposia.html, accessed 17 January 2010. The prefix nano means "one-billionth," thus a nanometer is one one-billionth of a meter.

[5] Joel Garreau, *Radical Evolution: The Promise and Peril of Enhancing Our Minds, Our Bodies – and What It Means to be Human* (New York: Broadway Books, 2005), 118.

[6] M.C. Roco is Senior Advisor to the National Science Foundation and the U.S. National Science and Technology Council's Subcommittee on Nanoscale Science, Engineering and Technology. He is the author of *International Perspective on Government Nanotechnology Funding in 2005*.

[7] David M. Berube, *Nano-Hype: The truth Behind the Nanotechnology Buzz*, (Amherst, New York: Prometheus Books, 2006), 15.

[8] These properties include conductivity and speed of transmission of light that vary according to the direction in which they are measured.

[9] M. J. Bonder, Y. Huand, and G. C. Hadjipanayis, "Magnetic Nanoparticles," in *Advanced Magnetic Nanostructures*, eds. D. Sellmyer and R. Skomski (Berlin: Springer, 2005), 21. http://books.google.com/books?id=t7SGkTAJdRgC&pg=PP1&dq=advanced+magnetic+nanostructures#PPA183,M1

[10] J. Storrs Hall, *Nanofuture: What's Next for Nanotechnology* (Amherst, New York: Prometheus Books, 2005), 21.

[11] "Science and technology are always heavily intertwined and impossible to discuss, or indeed to advance, independently. Understanding the science enables the technology, and harnessing the technology allows further advances in the science." National Research Council of the National Academies, *Implications of Emerging Micro- and Nanotechnologies* (Washington D.C.: The National Academies Press, 2002), 22-23.

[12] Dr. Neal Lane, National Science Foundation Director, quoted in testimony before Congress on April 1, seeking support for his $3.8 billion fiscal year 1999 budget request. http://www.foresight.org/Updates/Update33/Update33.1.html. During this testimony he also said, "NSF support over the years has allowed nanoscale science and engineering to go from the realm of science fiction to science fact. One of the most notable NSF-supported discoveries was the Nobel Prize winning discovery... of a hollow form of carbon known as Buckyballs. Subsequent research has shown that a related class of molecules--the fullerenes--can form 'nanotubes' only a few atoms in diameter that could be the basis for a stunning array of new environmentally friendly, carbon based materials never known before. The possibilities of nanotechnology are endless."

[13] M.C. Roco conceived a generalized future path of nanotechnology categorized into four generations of products: passive and active nanostructures, systems of nanosystems, and molecular nanosystems. M.C Roco, "

International Perspective on Government Nanotechnology Funding in 2005," *Journal of Nanoparticle Research*, Vol. 7(6), (2005), 1. Available at http://www.nsf.gov/crssprgm/nano/connections/international/perspectives.jsp

[14] The President signed the 21st Century Nanotechnology Research and Development Act, or Public Law 108-153, in December 2003 creating a National Nanotechnology Institute. Many governments are investing in nanotechnology. The United Kingdom has a National Initiative on Nanotechnology. The king of Saudi Arabia founded the King Abdullah Nanotechnology Initiative and funded three corresponding nanotechnology centers. King Abdullah Nanotechnology Initiative Website, http://faculty.ksu.edu.sa/hisham/Nanotechnology/Pages/KAInitiative.aspx, accessed 17 January 2010. There is also a very active European Nanotechnology Gateway. The Iranian government is also very interested in nanotechnology. In 2004 they held their first joint nanotechnology conference with Germany and in 2008 had a major joint conference with India. Overall in 2003 there was a worldwide investment of over $3 billion in nanotechnology R&D. "Summer Story Stocks," *Nanotech Report* 2, no. (7 July 2003), 4. Between 1997 and 2005, global investment in nanotechnology R&D, reported by national government organizations and EC, increased nine-fold from $432 million to about $4.1 billion. Roco, "International Perspective on Nanotechnology," 1.

[15] "It's the economic imperative of a competitive market that is the primary force driving forward and fueling the law of accelerating returns. … Economic imperative is the equivalent of survival in biological evolution." Ray Kurzweil, *Singularity is Near: When Humans Transcend Biology (New York, NY, Penguin Books*, 2005), 96.

[16] Berube, *Nano-Hype*, 22.

[17] James Watson and Francis Crick discovered the structure of Deoxyribonucleic acid (DNA) in 1953.

[18] Self-replication is when nanoscale machine factories produce nanoscale machines in a self-replicating loop. K. Eric Drexler is an American engineer and futurist credited with the concept of nanotechnology, though he now refers to his idea of nanotech as molecular manufacturing to distinguish it from the current non-specific usage of nanotechnology. "The key idea about his vision of nanotech is the creation of assemblers." Assemblers are machines that precisely place individual atoms when making an item. As any item requires billions of atoms the first step in mass production is to build more assemblers. Garreau, *Radical Evolution*, 121.

[19] Mark C. Suchman, "Social Science and Nanotechnology," presented to the 3rd EC/NSF Workshop on Nanotechnology: Revolutionary Opportunities and Societal Implications in Lecce, Italy, (2002), 1.

[20] Ray Kurzweil postulates full-scale nanotechnology in the 2020s enabling humans to "replace biology's genetic-information repository in the cell nucleus with a nanoengineered system" to maintain the genetic code and simulate cell actions like RNA (ribosome). Kurzweil, *Singularity is Near*, 232.

[21] See Note 14 for information on global investment in nanotechnology.

[22] Zinc oxide nanorings formed by self-coiling of nanobelts may be useful for investigating polar surface-induced growth processes, fundamental physics phenomena, and nanoscale devices. "INL, ISU Team on Nanoparticle Production Breakthrough," *Nanotechwire.Com*, (21 October 2009), 1. Available at http://www.nanotechwire.com/news.asp?nid=8804

[23] M.C. Roco, "Frontiers for Nanomanufacturing," presentation at Next Generation Material for Defense in Arlington, VA (10 December 2008), slide 13.

[24] Dr Michael A. Meador, "Nanostructured Material for Aerospace Power and Propulsion," presentation at Next Generation Material for Defense in Arlington, VA (10 December 2008), slides 2, 3, 26, 44.

[25] *Chang-Cheng You, Oscar R. Miranda, Basar Gider, Partha S. Ghosh, Ik-Bum Kim, Belma Erdogan, Sai Archana Krovi, Uwe H. F. Bunz & Vincent M. Rotello, "*Detection and Identification of Proteins using Nanoparticle–

fluorescent Polymer 'Chemical Nose' Sensors," *Nature Nanotechnology 2*, (22 April 2007), published online *http://www.nature.com/nnano/journal/v2/n5/abs/nnano.2007.99.html. Accessed 30 January 2010.*

[26] "The carbon nanotube is a now well-defined nanostructure, and exploring ways to exploit its unique properties for possible nanotechnology-based applications remains a subject of intense interest." National Research Council of the National Academies, *Implications of Emerging Micro- and Nanotechnologies* (Washington D.C.: The National Academies Press , 2002), 48.

[27] National Research Council of the National Academies, *Implications of Emerging Micro- and Nanotechnologies* (Washington D.C.: The National Academies Press , 2002), 47. "Discovered in 1991, tubular structures of carbon had been predicted since the discovery of soccer-ball-shaped 60-carbon molecules (buckminsterfullerenes, or 'buckyballs') in 1985 at Rice University." …. "Depending on their diameter and chirality, nanotubes exhibit either metallic (like copper) or semiconducting behavior." National Research Council, *Implications of Emerging Micro*, 47.

[28] National Research Council, *Implications of Emerging Micro*, 47.

[29] Jennifer Ouellette, *Building the Nanofuture with Carbontubes: Broad Commercialization Awaits Fabrication Advances,* (The Industrial Physicist, published online: http://www.aip.org/tip/INPHFA/vol-8/iss-6/p18.html). Accessed 30 January 2010.

[30] M. Meyyappan, "An Overview of Recent Developments in Nanotechnology," slide 6, http://www.ipt.arc.nasa.gov.

[31] "Magnetic Nanoparticles," University of Delaware, Department of Physics and Astronomy, http://web.physics.udel.edu/research/nanoscale-physics/magnetic-nanoparticles, accessed 17 January 2010.

[32] "INL, ISU Team Breakthrough", *Nanotechwire.Com*, 1.

[33] For example the INL and Idaho State University team have reported great progress with their Precision Nanoparticles, "INL, ISU Team Breakthrough", *Nanotechwire.Com*, 1.

[34] Hall, *Nanofuture*, 45-46.

[35] Hall, *Nanofuture*, 47.

[36] Radiation Shield Technologies advertises Demron™ as the new standard in personal radiation protection. It not only protects against particle ionizing/nuclear radiation (such as Beta and Alpha), but shields against X-ray and low-energy Gamma emissions. Demron™ suits are constructed from a unique nanotechnology that far surpasses the effectiveness of current nuclear-biological-chemical suits that only protect against radioactive particulate sources. http://www.radshield.com/, accessed 17 January 2010.

[37] Hall, *Nanofuture,* 46.

[38] Bonder, Huand, and Hadjipanayis, "Magnetic nanoparticles", 28. http://books.google.com/books?id=t7SGkTAJdRgC&pg=PP1&dq=advanced+magnetic+nanostructures#PPA183,M1 , accessed 17 January 2010.

[39] Jonathan Strickland, *How Nanowires Work*, (How Stuff Works, published on-line at http://science.howstuffworks.com/nanowire4.htm), accessed 30 January 2010.

[40] Lynn E. Foster, *Nanotechnology: Science, Innovation, and Opportunity* (Upper Saddle River, NJ: Prentice Hall, 2006), XI.

[41] Roco, "International Perspective on Nanotechnology," 1-9.

[42] Kurzweil, *Singularity is Near*, 115.

[43] Computer simulated picture of carbon nanotube gears. CNTs are currently grown in the laboratory through several techniques and are just a few nanometers in diameter and several microns long. CNT exhibits extraordinary mechanical properties: the Young's modulus is over 1 Tera Pascal. It is stiff as diamond. The estimated tensile strength is 200 Giga Pascal. These properties are ideal for reinforced composites, nanoelectromechanical systems (NEMS). Http://www.ipt.arc.nasa.gov/carbonnano.html, accessed 17 January 2010.

[44] Georgia Institute of Technology, "The importance of Nanotechnology," http://www.nano.gatech.edu/about/, accessed 17 January 2010.

[45] "Long before the term 'nanotechnology' became commonplace, the benefits of manipulating the grain structure of materials on the nanoscale were known and exploited…. These nanostructured materials can provide for stronger, more durable, and more stable structures. …. The classic model for how strength of metals increases as grain size decreases describes the pileup of dislocations at grain boundaries, producing stress, which when added to applied stress results in slippage across the boundary. Smaller grains results in a smaller pileup of dislocations and less stress, with a larger external force needed to create slippage (and therefore a stronger material)." National Research Council, *Implications of Emerging Micro*, 105.

[46] K. Eric Drexler, "Molecular Engineering: An Approach to the Development of General Capabilities for Molecular Manipulation," (Proceeding of the National Academy of Science, Vol. 78, No. 9, pp. 5275-5278, September 1981), pg 5275.

[47] M. Meyyappan, "Nanotechnology: Opportunities and Challenges," slide 14. http://www.ipt.arc.nasa.gov, accessed 9 December 2009.

[48] Meyyappan, "Nanotechnology: Opportunities and Challenges," slide 14.

[49] Meyyappan, "Nanotechnology: Opportunities and Challenges," slide 14.

[50] Meyyappan, "Nanotechnology: Opportunities and Challenges," slide 14.

[51] This image was created to show one of the possible applications of nanotechnology in medicine in the future - microscopic machines roaming through the body, injecting or taking samples for tests "Nanotechnology Picture Scoops Prize," Nanotechweb.org, 24 Sep 02. A nanotechnology image has won first prize in the "Science Concepts" section of the 2002 Visions of Science Awards. The image shows a nanomedicine application, in which a "nano-louse" device administers treatment to red blood cells. Coneyl Jay, a photographer and illustrator, used computer graphics to produce the picture. The judging panel said the nano-louse image, with its pincers and in-built syringe, cleverly conveys the idea of nanomedicine. *Nanotechwire.Com*, http://nanotechweb.org/cws/article/tech/9929, accessed 13 January 2010.

[52] Hall, *Nanofuture,* 34.

[53] Richard W. Oliver, *The Biotech Age: The Business of Biotech and How to Profit From It*, (New York: McGraw-Hill, 2003), Xii. Oliver describes biotech as "that part of bioterials (biomaterials) concerned with biological technologies.

[54] Oliver, *Biotech Age*, 139.

[55] Dr James Murday, "Nanomaterials: Applications and Evolution," presentation at IDGA Advanced Material Applications (12 December 2008), slide 4.

[56] National Cancer Institute, NCI Alliance for Nanotechnology in Cancer, http://nano.cancer.gov/learn/understanding/faq.asp#q2, accessed 9 Jan 2010.

[57] National Cancer Institute, the sentences from “These devices are…” thru “…and within the cell,“ are also from this source.

[58] “Imagine your life being saved by a custom-designed medical machine made from particles 50,000 times as small as a single strand of your hair.” Dr James D. Meindi, Georgia Institute of Technology website, http://www.nano.gatech.edu/faculty-staff/profiles/meindl.php, accessed 17 January 2010.

[59] “Ubiquitous computing names the third wave in computing, just now beginning. First were mainframes, each shared by lots of people. Now we are in the personal computing era, person and machine staring uneasily at each other across the desktop. Next comes ubiquitous computing, or the age of *calm technology*, when technology recedes into the background of our lives. Alan Kay of Apple calls this "Third Paradigm" computing. Ubiquitous computing is roughly the opposite of virtual reality. Where virtual reality puts people inside a computer-generated world, ubiquitous computing forces the computer to live out here in the world with people.” http://nano.xerox.com/hypertext/weiser/UbiHome.html, accessed 10 Jan 2010.

[60] “The term ‘quantum devices’ refers to devices dominated by nonclassical effects arising from the discrete nature of matter at atomic dimensions and the resulting wave interference effects. …. It is already well accepted as a device capable of enhancing the speed of field –effect transistor logic devices by a factor of 2 to 5, allowing a significant increase in processing speed for digital signal processors.” National Research Council, *Implications of Emerging Micro*, 49.

[61] Meyyappan, “Nanotechnology: Opportunities and Challenges,” slide 5.

[62] QC will be a huge technological leap forward for mankind. It relies on controlling and observing the behavior of quantum particles or single electrons, to deliver phenomenal processing power at blinding speeds. The impact of QC will go beyond simple computing power, but will synergistically affect a tremendous number of other fields. Niels Bohr said “Anyone who is not shocked by the quantum theory does not understand it.”

[63] Kurzweil, *Singularity is Near*, 27.

[64] Bonder, Huand, and Hadjipanayis, “Magnetic nanoparticles”, 183.

[65] Marcia Riley, “Ubiquitous Computing: An Interesting New Paradigm,” Georgia Institute of Technology, http://www.cc.gatech.edu/classes/cs6751_97_fall/projects/say-cheese/marcia/mfinal.html, accessed 10 Jan 2010.

[66] The technique uses nanoparticles to sense other nanoparticles and so identify the particle’s chemical. Sensors can use nanotechnology in two ways. They can be used to detect and study nanoparticles, but they can also employ nanoparticles and the process of their formation as a sensor system “utilizing the nanoparticles itself as a basis of detecting other chemicals and materials.” “The detection of gases, for example, can use the formation of nanoparticles as detectors for the gas of interest. Chemical species that are formed in this manner as the basis of the sensor system are nanosize in nature. ... The mechanism on which the two sensor applications are based also can be used to synthesize new nanoparticle systems.” Sensors Group, Lawrence Berkeley National Laboratory, http://sensors.lbl.gov/sf_nano.html, accessed 13 January 2010.

[67] Altmann, *Military Nanotechnology*, 78.

[68] Altmann, *Military Nanotechnology*, 74.

[69] Michio Kaku, *Visions*, (New York, Anchor Books, 1997), 26.

[70] Nanotechnology Gallery, http://www.ipt.arc.nasa.gov/datastorage.html, accessed 15 January 2010.

[71] "Avoiding Technology Surprise for Tomorrow's Warfighter: A Symposium Report," (Washington D.C., The National Academies Press, 2009), 28. http://www.nap.edu/catalog.php?record_id=12735, accessed 17 January 2010.

[72] Another possible avenue for nanotechnology-enabled armour is cast metal matrix composites (MMCs), which are cheaper, lighter and stronger than their original alloys. MMCs could lead to "… tanks that are light enough to be airlifted, but are just as rugged as the much heavier varieties. … A nanostructured aluminium can be 10 times stronger than conventional aluminium alloys." In fact the University of Wisconsin-Milwaukee has created an aluminIum-based MMC that can replace iron-based alloys. These composites have many applications in the transportation, small engines, aerospace and computer industries. MMCs combine metal with a totally different class of material like ceramics or recycled waste resulting in "amazing structural and physical properties not available in the natural world." Adaptation of a conventional foundry process to synthesize aluminium and graphite "slashed the cost of mass-producing MMCs and allowed for more complex shapes to be made." R&D in MMCshas focused on "reinforcing aluminium with elements such as graphite and silicon carbide particles (ceramics) to form materials that are 20–40% stronger." The U.S. Army has been funding R&D efforts to develop lighter, heavy-duty materials to meet their need for airliftable vehicles able to operate for prolonged periods without refueling. Nanotechnology World, http://www.nanotechnologyworld.co.uk/content/view/456/1/, accessed 13 January 2013.

[73] Altmann, *Military Nanotechnology*, 76.

[74] Altmann, Military Nanotechnology, 77.

[75] Altmann, *Military Nanotechnology*, 76.

[76] Murday, "Nanomaterials: Applications and Evolution," slide 10.

[77] Energetic materials consist of fuels and oxidizers which are intimately mixed. And nanotech is currently being investigated as the answer to technological barriers to development, such as the "existing limitation of processing granular solids is in manufacturing energetic materials for detonators. The state-of-the-art now requires the precise synthesis and recrystallization of explosive powders." "Novel Energetic Materials," Global Security, 1. http://www.globalsecurity.org/military/systems/munitions/novel-energetic-materials.htm, accessed 17 January 2010. The finer a power is the better it will mix and nanoparticles are the ultimate in fine power. Advances in controlling nanoparticles are continually being made. In October 2009 Idaho National Laboratory and Idaho State University chemists announced they'd "invented a way to manufacture highly precise, uniform nanoparticles to order." "INL, ISU Team Breakthrough", *Nanotechwire.Com*, 1. http://www.nanotechwire.com/news.asp?nid=8804). Historically, explosives from black powder to trinitrotoluene (TNT) have required mixing oxidizers with a fuel source to create a composite energetic material or incorporating "oxidizing and fuel moieties into one molecule, referred to as monomolecular energetic materials." "Novel Energetic Materials," Global Security, 1.

[78] Murday, "Nanomaterials: Applications and Evolution," slide 10.

[79] "Yes it is possible to use nanoparticles as taggants to track, but the toxicity issues of NPs is still not clearly understood. But clearly there are stand-off detectors that can be used to detect NPs in cluttered environments." Dr Jonathan E. Spowart, Senior Materials Research Engineer, USAF Research Laboratory, Materials Manufacturing Directorate, Wright-Patterson AFB, IL, to this author, e-mail, 23 December 2010.

[80] Human-terrain mapping creates a political, economic, and social map or human-terrain picture designed to create a better understanding of the local population. This information is then used to demonstrate a

commitment to improving local communities as well as enabling more proactive initiatives and faster, much more effective responses to events. The map is really an "outline of who the players in the current game" are. Jack Marr, John Cushing, Brandon Garner, and Richard Thompson, "Human Terrain Mapping: A Critical First Step to Winning the COIN Fight," *Military Review*, March-April 2008, 19-20.

[81] Marr, Cushing, Garner, Thompson, "Human Terrain Mapping," 1.

[82] This paper postulates that current global investments in medical nanoparticles will have made available nanoparticles safe for use in tagging humans by 2035. See Note #14 for information on global investments in nanotechnology.

[83] One relevant cutting edge area of study is in highly uniform gold nanoparticles, which allow scientists to understand how nanoparticles lose energy. This is "a key step towards producing nanoscale detectors for weighing any single atom." "Novel Energetic Materials," Global Security, 1. http://www.globalsecurity.org/military/systems/munitions/novel-energetic-materials.htm. Weighing atoms is also an important step toward improving manipulation of individual atoms leading to nanotaggants. Other breakthroughs in understanding nanoparticles are continuously being made, for example Argonne National Laboratory scientists have created tools to observe "molecular-scale features, measuring less than a nanometer in height." "Breaking the Nanometer Barrier in X-ray Microscopy," *Nanotech Wire* (14 November 2006).

[84] The AEROTRAK™ 9000 Nanoparticle Aerosol Monitor determines the "surface area of nanoparticle aerosols that deposit in the lung." It is portable and battery-operated with real-time readout and data logging capability. TSI Incorporated website, http://www.tsi.com/en-1033/products/2320/aerotrak%e2%84%a2_9000_nanoparticle_aerosol_monitor.aspx, accessed 13 January 2010.

[85] Sensors Group, Lawrence Berkeley National Laboratory, "Nanoparticle Sensors and Nanoparticle-Based Detector Systems," 1. http://sensors.lbl.gov/sf_nano.html accessed 13 Nov 09

[86] "Researchers: Molecular Forklifts Overcome Obstacle to 'Smart Dust'," *Nanotechwire.Com*, (1 January 2009). This author also observed these type quantum dots at the AF Research Laboratory Sensors Directorate when researching this paper, during a Center for Strategy and Technology research trip to Wright-Patterson AFB, 22 September 2009.

[87] The Molecular Foundry is a national nanoscience research facility at Berkeley National Laboratories funded by the U.S. Department of Energy. http://foundry.lbl.gov/index.html, accessed 17 January 2010.

[88] "Quantum dots, also known as nanocrystals, are a special class of materials known as semiconductors, which are crystals composed of periodic groups of II-VI, III-V, or IV-VI materials. Semiconductors are a cornerstone of the modern electronics industry and make possible applications such as the Light Emitting Diode and personal computer. Semiconductors derive their great importance from the fact that their electrical conductivity can be greatly altered via an external stimulus (voltage, photon flux, etc), making semiconductors critical parts of many different kinds of electrical circuits and optical applications. Quantum dots are unique class of semiconductor because they are so small, ranging from 2-10 nanometers (10-50 atoms) in diameter. At these small sizes materials behave differently, giving quantum dots unprecedented tunability and enabling never before seen applications to science and technology." Evident Technologies: Reinventing the Semiconductor, http://www.evidenttech.com/quantum-dots-explained/how-quantum-dots-work, accessed 13 January 2010.

[89] Another possible means for tracking nanotaggants may come from current research into fluorescent nano-tags. "It is expected that the combination of magnetic and fluorescent properties in one nanocomposite would enable

the engineering of unique multifunctional nanoscale devices." Serena A. Corr, "Multifunctional Magnetic-fluorescent nanocomposites," *Nano Review*, (6 March 2008), 1.

[90] "The general terms 'high context' and 'low context' (popularized by Edward Hall) are used to describe broad-brush cultural differences between societies. A high context culture refers to societies or groups where people have close connections over a long period of time. Many aspects of cultural behavior are not made explicit because most members know what to do and what to think from years of interaction with each other." Examples of high context cultures are Afghanistan, Pakistan or Yemen. Culture at Work.Com, http://www.culture-at-work.com/highlow.html, accessed 17 January 2010.

[91] DOD Dictionary of Military Terms, http://www.dtic.mil/doctrine/dod_dictionary/?zoom_query=deterrence&zoom_sort=0&zoom_per_page=10&zoom_and=1, accessed 17 January 2010.

[92] An underlying assumption to this discussion is US leadership in nanotechnology in general and nanoparticle manufacturing in particular.

[93] CSA General Gordon Sullivan, U.S. Army, remarks, publisher not given, 1993, 7-1, on-line at https://akocomm.us.army.mil/usapa/doctrine/Dr-pubs/dr_aa/pdf/fm63_11.pdf.

[94] Intelligence used here means identifying the what, why, who and how of adversaries and the threats they pose.

[95] John Smart, interviewed by the author,28 October 2009 at the Center for Strategy and Technology offices, Maxwell AFB.

[96] See Note 80 for discussion on the relevant concept of Human Terrain System.

[97] Jeffrey W. Knopf, "Three Items in One: Deterrence as Concept, Research Program, and Political Issues," in *Complex Deterrence: Strategy in the Global Age*, edited by T.V. Paul, Patrick M. Morgan, and James J. Wirtz, (Chicago, The University of Chigaco Press, 2009), 40.

[98] "Nanotechnology provides possibilities of protection against chemical or biological weapons." Nanotechnology could be used to improve sensing equipment leading to earlier detection. It might also be used to "block molecules by pores…(or) degrade or destroy the agents, often by the large surface area of catalytic nanomaterials. The latter two could be used in filters for gas masks, air intakes etc." Altmann, *Military Nanotechnology*, 103.

[99] In addition to preventive arms control civilian society also has rules covering R&D to limit technological progress and new goods into the market. Altmann, *Military Nanotechnology*, 119.

[100] Patrick M. Morgan, "Collective-Actor Defense," in *Complex Deterrence: Strategy in the Global Age*, edited by T.V. Paul, Patrick M. Morgan, and James J. Wirtz, (Chicago, The University of Chigaco Press, 2009), 158.

[101] Due to its fungibility these successes have formed a self perpetuating innovation loop. For example, biotech companies are funding advances in nanotech to provide new tools to produce better pharmaceuticals. These advances in nanotech are then applied to the science of computing which then circles back to improve researchers' clarity on critical medical issues like Deoxyribonucleic acid (DNA).

[102] Omar Khayyam, *Rubaiyat of Omar Khayyam* (NY: Random House, 1947), 35.

[103] It did however, list nanometer, but said "See Angstrom." The Concise Columbia Encyclopedia, Columbia University Press, New York, 1983, 557.

[104] Columbia Encyclopedia 2010, Encyclopædia Britannica Online, http://www.britannica.com/bps/search?query=nanotechnology. Accessed 16 February 2010.

[105] Feyman, discussion, http://www.its.caltech.edu/~feynman/, accessed 31 January 2010.